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TITLE PAGE:

Outcomes of Anesthesiologist led care of patients following liver transplantation during the COVID-19 pandemic

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ABSTRACT:

Background: At the start of the COVID-19 pandemic, many medical centers curtailed transplantation services to conserve resources. However, the redeployment of non-ICU trained anesthesiologists as transplant intensive care unit intensivists coupled with the introduction of several workflow adjustments allowed for the continuation of liver transplantation throughout the pandemic.

Methods: Patients who underwent liver transplantation at a tertiary care teaching hospital from December 28, 2015 through May 1, 2020 were identified and grouped according to whether they underwent liver transplantation before March 3, 2020 (controls) or after March 3, 2020 (cases). Propensity scoring using Inverse probability of treatment weight (IPTW) was used to measure differences in baseline characteristics, and Cox proportional hazards regression analysis was used to evaluate the influence of workflow changes on Transplant ICU (TLOS) and HLOS.

Results: 523 liver transplant patients (30 cases, 493 controls) were included. Kaplan-Meier survival curves showed no significant difference in TLOS (median LOS 3.8 vs. 4.5 days, log-rank P = 0.60) and HLOS (median LOS 14.2 vs. 14.5 days, log-rank P = 0.66) between groups. Cox proportional hazards regression with IPTW showed no difference in TLOS (hazard ratio, 0.91; 95% CI, 0.67 to 1.23; P = 0.55) or HLOS (hazard ratio, 0.90; 95% CI, 0.65 to 1.25, P = 0.52).

Conclusions: There was no difference in TICU or hospital LOS between the COVID era and pre-COVID era. The results suggest that the non-intensivist anesthesiologist led TICU care offers a safe and effective care model during a pandemic emergency.

Word Count: *245*

Abbreviations: SOT – solid organ transplantation, OLT – orthotopic liver transplantation, LDLT – Living donor liver transplantation, PACU – post anesthesia care unit, ICU – intensive care unit, TICU – transplant intensive care unit, Virtual transplant intensive care unit (V-TICU), TLOS – transplant intensive care unit length of stay, HLOS – hospital length of stay, RT-PCR – reverse transcriptase polymerase chain reaction, CT – computed-tomography, BMI – body mass index (BMI), HIPPA – Health Insurance Portability and Accountability Act, MELD – Model for End Stage Liver Disease

Key Words: liver transplant, organ transplant, anesthesiology, critical care, intensive care unit, COVID-19, pandemic, workflow

INTRODUCTION:

The novel coronavirus infectious disease 2019 (COVID-19), and the ensuing pandemic has impacted US healthcare systems, necessitating the reallocation of healthcare resources in order to meet new system-wide demands.[1–3] COVID-19 has disproportionately impacted specific patient populations including the elderly, patients with comorbid medical conditions, and the immune compromised, in whom COVID-19 is associated with increased risk of severe morbidity and mortality.[4–6] Providing safe and adequate non-COVID-19 related medical services for patients who fall into these high risk categories is a major concern and a complex issue for many tertiary medical centers.

Concern for increased mortality from COVID-19 among immune compromised patients[6] likely contributed to a nation-wide reduction in solid organ transplantation (SOT), including heart, kidney and liver at the start of the pandemic.[7–10] As hospitalizations rapidly increased, the

reallocation of intensivists and intensive care unit (ICU) beds to care for COVID-19 patients also played a role in reducing SOT.[11,12] During the initial months of the pandemic in the US (2/6/2020-4/10/2020), the United Network for Organ Sharing data revealed a 51.1% reduction in deceased donor organ transplant.[13] Concurrently, liver transplant centers in states with the highest incidence of COVID-19 hospitalizations experienced a 59% increase in waitlist mortality.[10] Because of this, current recommendations argue for the implementation of new protocols to allow for continued liver transplantation amidst the COVID-19 pandemic.[14]

This study outlines the approach at a major tertiary academic medical center in New York City, NY for continuing to provide orthotopic liver transplantation (OLT) services throughout the early phase of the COVID-19 pandemic. This study examines the effect of hospital workflow adjustments on postoperative outcomes – specifically transplant intensive care unit (TICU) length of stay (TLOS) and hospital length of stay (HLOS) – in patients undergoing OLT during the COVID-19 pandemic.

METHODS:

This retrospective study was approved with a waiver of informed consent from the Program for the Protection of Human Subjects at the Icahn School of Medicine at Mount Sinai (IRB study number STUDY-20-00629-CR001). Additionally, a separate COVID-19 research committee reviewed and approved this study. This manuscript adheres to the applicable Consensus-based Clinical Case Reporting (STROBE) guidelines.[15]

COVID Transplant Care Model:

Between March 3, 2020 and May 1, 2020, our institution implemented a series of multidisciplinary changes that allowed the transplant program to continue functioning within the constraints imposed by the COVID-19 pandemic. The changes can be generalized into three broad categories: (1) resource allocation, (2) infection prevention, (3) transplant candidate and donor selection.

1. Resource Allocation:

In response to a rapid increase in COVID-19 admissions requiring ICU care, our institution's TICU was converted to a COVID-19-only unit. In addition, all fellowship-trained intensivists, critical care fellows and mid-level providers that normally staff the TICU were redistributed throughout the hospital system to staff COVID-19 units. New multidisciplinary workflows were implemented in accordance with our institution's COVID-19 infection prevention protocol to maintain the safety of staff and patients.

Following the New York State-directed suspension of elective surgery in March 2020, one of the three post anesthesia care units (PACU) was repurposed to serve as a fully functional "virtual" TICU (V-TICU) and designated as a COVID-19 free ICU. Non-intensivist, liver transplant-specialized anesthesiologists assumed the day-to-day critical care management of patients receiving pre- and post-transplant. Transplant surgeons, hepatology, infectious disease, and nephrology attending physicians and fellows were incorporated into the daily care team and consulted on a regular basis to assist with the management of patients during the post-transplant period. In addition, the V-TICU was staffed by two anesthesiology residents who provided 24-hour coverage, 7 days per week. In the first 24 hours post-transplant, patients were cared for in a

1:1 ICU trained nurse-to-patient ratio. High acuity patients continued to receive coverage by ICU-trained nurses throughout their V-TICU admission, while hemodynamically stable patients were covered by a PACU-trained nurse, at the discretion of the V-TICU attending.

2. Infection Prevention:

All transplant candidates were required to demonstrate two negative COVID-19 reverse transcriptase polymerase chain reaction (RT-PCR) nasopharyngeal tests prior to admission to the TICU. An additional negative COVID-19 RT-PCR test in the immediate preoperative period as well as a thorough assessment ruling out signs or symptoms of infection was required prior to transplantation. Following surgery, OLT patients were transferred directly from the operating room to the TICU. During the pre- and post-operative periods, all patients admitted to the TICU underwent daily screening for signs and symptoms of COVID-19 infection. Any patient with new symptoms including cough, dyspnea, fever, and chills underwent additional COVID-19 RT-PCR testing. Non-contrast chest computed-tomography (CT) was employed in select cases to assess for COVID-19 infection when nasopharyngeal RT-PCR testing was negative but the clinical picture was highly suspicious for infection. In the event of a positive test or presence of concerning findings on pulmonary imaging, the patient was immediately transferred to a COVID-19 designated unit. Patients who tested positive for COVID-19 were deferred for transplantation until the resolution of their infection as defined by two negative RT-PCR tests as well as a CT demonstrating no active pulmonary findings. Regardless of prior testing status, all patients undergoing transplantation were required to undergo rapid COVID-19 testing with a negative test within 48 hours of surgery. See figure 3 for an outline of the COVID-19 screening algorithm implemented during this period.

Given the unknown effects of COVID-19 on organ viability and graft function, organ procurements were restricted to COVID-19 negative donors. All donors were screened via nasopharyngeal swab with RT-PCR testing and chest CT to rule out infection. It was required that both tests were negative to accept the donor graft.

In order to reduce risk of exposure for both patients and providers, all meetings, including multidisciplinary rounds, recipient selection, educational conferences and family meetings were held virtually. All screening visits for outpatient OLT referrals as well as post-discharge visits following transplantation were performed remotely using a Health Insurance Portability and Accountability Act (HIPAA) secure video platform. In-person visitation was suspended for all adult patients. Staff members were required to wear N95 masks, eye protection, and scrubs while working in patient facing areas. Upon entry to any hospital facility, staff members were required to fill out an electronic survey that screened for symptoms related to COVID-19 as well as exposure status. As an additional safety measure, staff underwent temperature checks prior entry into the V-TICU. Any staff member who experienced an asymptomatic exposure or reported symptoms related to COVID-19 were screened for COVID-19 with a SARS-CoV-2 RT-PCR test. Symptomatic staff members were required to quarantine until results were available. In the event of a positive test, staff members were quarantined for a minimum of 10 days from symptom onset, and not allowed to return to work until cleared by Employee Health Services.

3. Transplant Candidate and Donor Selection:

With the exception of deferring COVID-19 positive patients, no changes were made to the institution's standard candidate selection criteria. While efforts were made to prioritize transplantation in high-risk candidates, including those with HCC, MELD > 30 and patients in fulminant hepatic failure, any candidate could be transplanted. Living donor liver transplantation (LDLT) was temporarily suspended from March 23, 2020 – May 1, 2020.

Study Population & Data Collection:

Patients who underwent OLT from December 28, 2015 through May 1, 2020 were identified, and screened for enrollment, including simultaneous liver-kidney transplants and re-transplant cases. Transplants that occurred during COVID period (March 3, 2020 – May 1,2020), were included as our population of interest (cases). Transplants that occurred in the pre-COVID period (December 28, 2015 – March 3, 2020) included as controls.

Patient characteristics associated with liver transplantation outcomes were retrieved from departmental and hospital warehouses as well as electronic medical records. These data were used as covariates in subsequent analyses and included patient demographics such as age, gender, body mass index (BMI); and medical comorbidities including coronary artery disease, cardiac arrhythmias, hypertension, diabetes mellitus, and chronic kidney disease.

Liver disease characteristics such as alcoholic cirrhosis, ascites, spontaneous bacterial peritonitis, variceal bleed, hepatic encephalopathy, hepatocellular carcinoma, hepatorenal syndrome, and Model for End Stage Liver Disease (MELD) score were included. In addition, transplantation characteristics such as transplant type, re-transplant, donor type were also included.

Outcome Measures:

The primary outcomes were TICU length of stay (TLOS) and total hospital length of stay (HLOS). Our independent variable of interest was date of transplant: pre-COVID vs. COVID.

Statistical Analysis:

In this descriptive analysis, a 2-sided t test for continuous variables and a $\chi 2$ test or Fisher's exact test for discrete variables were used to assess for differences in characteristics between groups. Kaplan Meier curves and log-rank tests were used to compare time to hospital discharge.

Propensity score modeling with inverse probability of treatment weighting (IPTW) was used to determine the association between V-TICU care during the COVID period with TLOS and HLOS as compared to traditional TICU care during the pre-COVID period. IPTW is a technique for estimating exposure effect standardized to a pseudo-population that removes confounding in observational studies. It relies on building a penalized logistic regression model with Firth's bias reduction method to estimate the probability of the COVID period exposure for each individual, and in subsequent analyses, using the inverse of the predicted probability as a weight. The penalized logistic regression model considered patient demographics and medical comorbidities along with liver disease characteristics, transplantation characteristics, and 4 categories of MELD scores (MELD < 20, MELD 20-29, MELD 30-39, MELD > 40). The inverse of the individual propensity score was assigned as weight for the patients in the COVID period, whereas the inverse of the 1 minus individual propensity score was assigned as weight for the patients in the pre-COVID period.

Additionally, several propensity score models were explored to determine the robustness of our results. In order to address extremely large or small propensity scores and the resulting extreme weights that may unduly influence results and yield estimates with high variance, we obtained stabilized weights to produce a suitable estimation of the variance of the main effect. However, the distribution of stabilized weights is still influenced by large weights for individual patients and large variability in the estimated treatment effect. Thus, we also employed a weight trimming approach to reduce weights greater than the 95^{th} quantile to the 95^{th} quantile and weights smaller than the 5^{th} quantile to the 5^{th} quantile to improve the performance of propensity score weighting. Finally, we ran each model with and without further adjustment with covariates for intracardiac defibrillator, hepatopulmonary syndrome, and porto-pulmonary hypertension – extremely rare factors that were not considered in the propensity score models since they caused model instability.

All analyses were performed with Rstudio[16] with R v4.1.1. (RStudio Team, Boston, MA). Cox proportional hazards regression analysis was used to evaluate the influence of workflow changes on TLOS and HLOS for post-liver transplant patients. All analyses included robust standard error calculations.

RESULTS:

Of 554 patients who underwent OLT between December 2015 and May 2020, 521 transplants occurred in the pre-COVID era while 33 transplants occurred in the COVID era. After removal of 25 patients due to incomplete datasets and 6 patients with rare factors for the cohort (intracardiac defibrillator, hepatopulmonary syndrome, or portopulmonary hypertension), inverse probability of treatment weighting yielded a final sample of 30 cases and 493 controls.

Table 1 shows the characteristics of the groups. There were no statistically significant differences in age, sex, BMI, TLOS, and HLOS between groups. There were also no differences in history of prior OLT, occurrence of simultaneous liver-kidney transplant and MELD score between cohorts. The prevalence of coronary artery disease, cardiac arrhythmias, hypertension, and chronic kidney disease, as well as liver disease characteristics such as alcoholic cirrhosis, ascites, spontaneous bacterial peritonitis, variceal hemorrhage, hepatic encephalopathy, and hepatorenal syndrome were higher in the COVID cohort. The prevalence of Type II diabetes mellitus and hepatocellular carcinoma was not significantly different between the two groups. There was a higher incidence of donation following brain death among pre-COVID cases while there was a higher incidence of donation following circulatory death among COVID cases (Table 1).

The median [IQR] TLOS and HLOS were 3.8 [2.6, 6.8] days and 14.2 [9.7, 23.9] days in the pre-COVID group, and 4.5 [3.0, 6.8] days and 14.5 [12, 34] days in the COVID group. The differences were not statistically significantly different (TLOS log-rank P = 0.60 and HLOS log-rank P = 0.66) (Figures 1 & 2). The traditional multivariable Cox regression revealed no significant association between the COVID era and TLOS when compared with pre-COVID era (hazard ratio, 0.63; 95% CI, 0.37 to 1.07; P = 0.09). There was no difference in HLOS between groups (hazard ratio, 0.66; 95% CI, 0.38 to 1.16, P = 0.15) (Table 2). The Cox regression analysis with inverse probability of treatment weighting with stabilized weights and trimmed weights also demonstrated that there was no significant association between the COVID era cases and TLOS (hazard ratio, 0.91; 95% CI, 0.67 to 1.23; P = 0.55) or HLOS (hazard ratio,

0.90; 95% CI, 0.65 to 1.25, P = 0.52) when compared to the pre-COVID era controls. This lack of statistically significant differences held across a variety of propensity score models (i.e. traditional unweighted, stabilized-only, stabilized & trimmed weights, with and without adjustment for rare covariates.

DISCUSSION:

Despite recommendations against the cessation of OLT during the COVID-19 pandemic,[14] and several studies demonstrating the ability to continue performing OLT without compromising short term outcomes,[17–21] there continued to be a significant reduction in OLT volume past the early stages of the pandemic.[10,22] In one international survey regarding physician attitudes towards the continuation of SOT during the pandemic, over 80% of respondents favored the selective or complete cessation of transplant services.[23] There was also significant variability among transplant centers in their response to the pandemic that could not be explained by regional infection rates alone.[11] This variability more likely reflected confusion or distrust in federal and state guidelines, as well as center-to-center differences in the prioritization of resources for continued OLT services relative to the management of COVID-19 patients.

In this analysis we used retrospective data from a single tertiary center in New York City to examine whether the novel workflow changes that were implemented to continue OLT during the first peak of the COVID-19 pandemic were associated with differences in short-term outcomes including TLOS and HLOS. The results showed no difference in TLOS or HLOS, suggesting that it was possible to continue performing OLT safely during the height of the COVID-19 pandemic.

Consistent with other recent publications,[12,15–19,22] the present study analyzed workflow changes to accommodate liver transplantation while in the midst of the COVID-19 pandemic. While centers varied in their approach, interventions were primarily focused on the redistribution of available resources, infection prevention, and recipient-donor selection. Several institutions reported the use of COVID-19 free spaces for the inpatient management of transplant patients.[17,20] However, the ability to maintain COVID-19 free transplant units likely varied given center-to-center differences in resource availability as well as regional differences in hospitalizations related to COVID-19. Following a rapid increase in ICU capacity, two New York City transplant centers reported being unable to maintain all transplant patients within COVID-19 free units.[24] Here, converting one of the PACUs into a designated COVID-19 free TICU allowed for the continued care of immunosuppressed transplant patients.

While much of the literature does not describe staffing changes during this time, one hospital in Westchester, NY did report that transplant surgeons assumed the care of patients during the post-operative period.[24] Here, transplant-specialized non-intensivist anesthesiologists assumed the care of patients undergoing OLT, allowing intensivists to focus on the management of COVID-19 patients. The anesthesiologists assigned to the TICU were not exposed to COVID-19 patients, this staffing change likely reduced the chance of provider-to-patient transmission.

Similar infection prevention measures were reported by institutions that continued to provide transplant services throughout the COVID-19 pandemic. Strategies included symptomatic and asymptomatic testing policies for clinical personnel, required quarantine in the event of a

positive result,[18,20] the use of virtual meeting platforms to limit in person interaction,[18–21,24] and either the suspension of, or a significant reduction in visiting hours.[17,19,20] Several institutions also reported the use of remote meeting platform for the outpatient screening of transplant referrals[18,21] as well as for completion of post-discharge follow-up visits.[18] In most cases, institutions required RT-PCR testing for COVID-19 as well as thoracic imaging to rule out a false negative infection in both donors and recipients.[17–21] Various protocols for regular symptomatic monitoring with repeat testing for hospitalized patients were also reported.[17–21] Most institutions refused grafts from COVID-19 positive donors,[17,18,20,21] and while there was some variation, in most cases OLT was deferred in recipients who tested positive for COVID-19.[17,20,21] In addition, several centers reported the temporary suspension of their LDLT programs.[20,21] One center that did continue to provide LDLT instituted a mandatory three-month postponement if donors tested positive for COVID-19.[17] In extenuating circumstances, where COVID-19 serology could not be obtained prior to surgery, one center proceeded with OLT in asymptomatic patients provided N95 respirators were worn by all staff members.[18]

In addition to COVID-19 status, acuity was also considered in the selection of transplant recipients. Citing concerns over ICU bed and ventilator availability, several centers opted to defer transplantation in patients perceived to have a high post-transplant mortality and therefore likely to experience a prolonged hospital stay.[18,20] One center noted that patients without cardiac and respiratory comorbid conditions were preferentially listed.[18] On the contrary, several institutions opted to prioritize transplantation in high risk patients whose three-month risk of mortality related to liver disease exceeded that of mortality related to COVID-19.[24] Similarly, one study noted the temporary suspension of non-urgent cases, citing the same concerns

regarding resource utilization.[21] While we did prioritize transplantation in patients with high mortality risk from liver disease, we did not take additional measures to suspend non-urgent cases. Because we chose not to delay transplantation on the basis of acuity or anticipated LOS, converting our PACU into a COVID-19 free unit designated for post-transplant care allowed for the space and staffing needed to care for these patients.

Optimal resource utilization and careful triage should be the guiding principles of patient care during the COVID-19 pandemic. The decision to continue providing high-resource utilizing services, such as OLT, should be made after careful consideration of the unique risks and benefits in doing so. Concern for a potential association between increased mortality from COVID-19 and factors such as reduced ICU bed capacity[25–27] and nursing availability,[27] likely influenced decisions regarding the suspension of transplant programs. Increased risk of mortality from infection among immunosuppressed patients[6] was an additional consideration among institutions who were unable to provide COVID-19 free spaces for post-transplant care. Furthermore, a nation-wide reduction in blood donation likely led to concern over maintaining adequate supply.[28]

The impact of differing strategies employed to triage OLTs has yet to be seen. For example, the preferential selection of low acuity cases may lead to increased waitlist mortality among more critically ill patients. On the contrary, as transplant rates return to normal, a subsequent reduction in graft availability may also lead to increased mortality among low acuity patients in whom transplantation was delayed. Given these risks, it is important that centers work together to ensure that SOT can continue safely. In one study, Michael's at al., suggests the redistribution of

waitlisted patients located in endemic regions to centers in less affected areas.[29] While doing so would require a high level of coordination between institutions, it would help limit the potential for regional disparities in care.

This study was unique in its description of non-intensivist, anesthesiologist-led peri-transplant care. Despite a lack of formal ICU training, the care that was provided during this time did not come at the expense of short-term outcomes. Anesthesiologists are experts in physiology including cardiopulmonary pathophysiology and resuscitation, mechanical ventilation, and caring for critically ill patients in the operating room and PACU. Despite this, the relative percentage of anesthesiologists that practice critical care medicine in America is low.[30] Given the current shortage of critical care doctors within the United States,[31] processes that facilitate the more active participation of anesthesiology departments in critical care settings, especially as it pertains to surgical-critical care, may help to address the shortage.

In designing this study, we attempted to limit potential sources of bias in the selection process. However, because of a relatively short study window, our results may have been biased by the small cohort of cases versus controls. This issue was addressed by utilizing multiple propensity score models. Given the retrospective nature of this study, it was difficult to control for all of the demographic characteristics of our cohort. There was a higher instance of comorbid conditions among the COVID cohort as compared to the pre-COVID controls. In addition, there was a higher incidence of donation following circulatory death among peri-pandemic cases while there was a higher incidence of donation following brain death among pre-pandemic cases. While these differences introduce a potential source of bias, we would have expected the effect to work

against our findings. Despite increased comorbid conditions and higher incidence of donation following circulatory collapse among the cohort of interest, there was no significant difference in TLOS or HLOS.

Our study focuses on immediate postoperative outcomes during the initial inpatient stay. We did not look at long-term outcomes including readmission, long-term mortality, and cost of care. Finally, this study was performed at a large tertiary academic medical center located in an urban setting. Therefore, these findings should be interpreted within the context of the setting that they were produced.

CONCLUSION:

In summary, our results suggest that during the initial wave of the COVID-19 pandemic, non-intensivist anesthesiologist-led care was associated with favorable post-OLT outcomes. This suggests that in future emergency events, utilization of this care model would allow for the continuation of OLT without compromising quality of care.

Word Count: 3,613

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Figure 1: COVID-19 screening algorithm for pre- and post-transplant patients

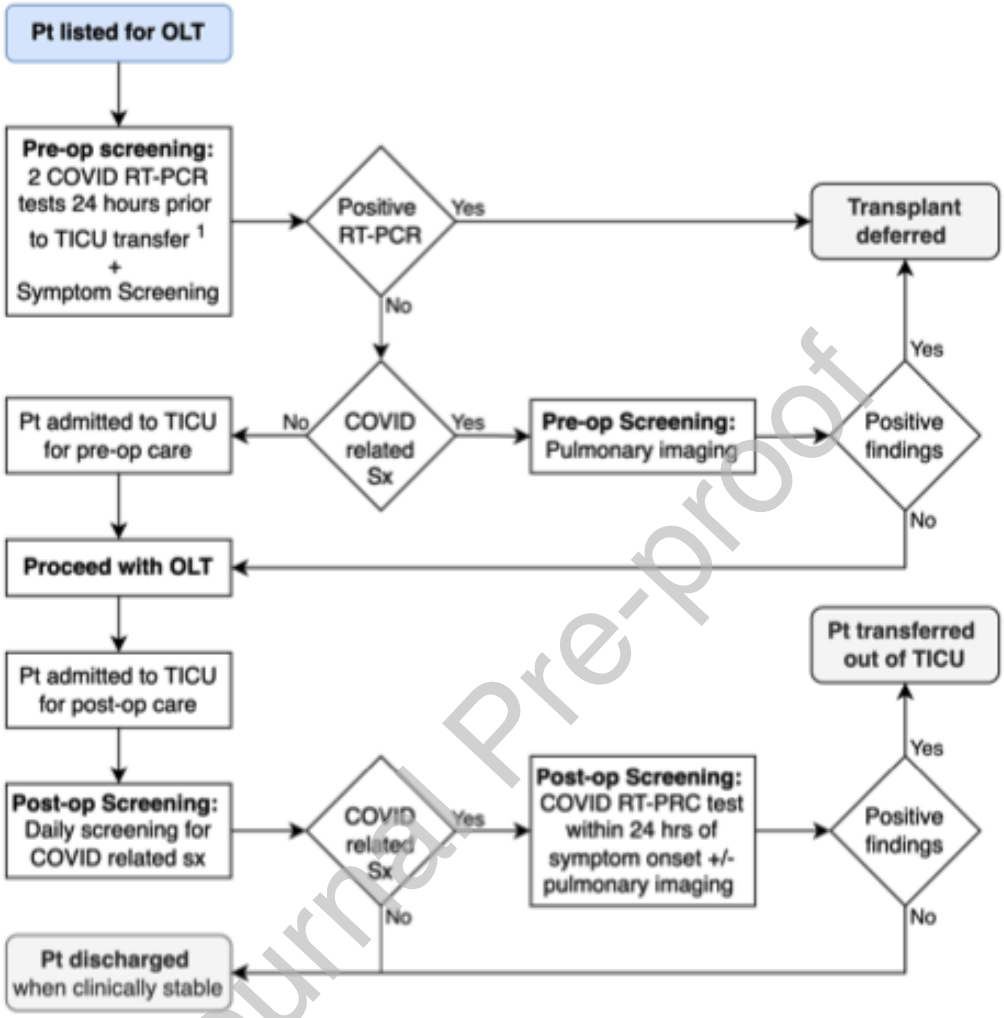

Figure 1: The flow diagram outlines the COVID-19 screening algorithm implemented during the pre- and post-transplant periods. In most cases, patients underwent transplantation within 48 hours of being admitted to the transplant ICU (TICU). In the event that a patient was admitted to the TICU more than 48 hours prior to surgery, they were retested for COVID-19 with a single RT-PCR nasopharyngeal swab.

OLT, orthotopic liver transplant; Pt, patient; Sx, symptoms; Pre-op, preoperative; post-op, postoperative.

Figure 2: Kaplan-Meier survival curve of N-TICU length of stay for pre-COVID and COVID groups following OLT

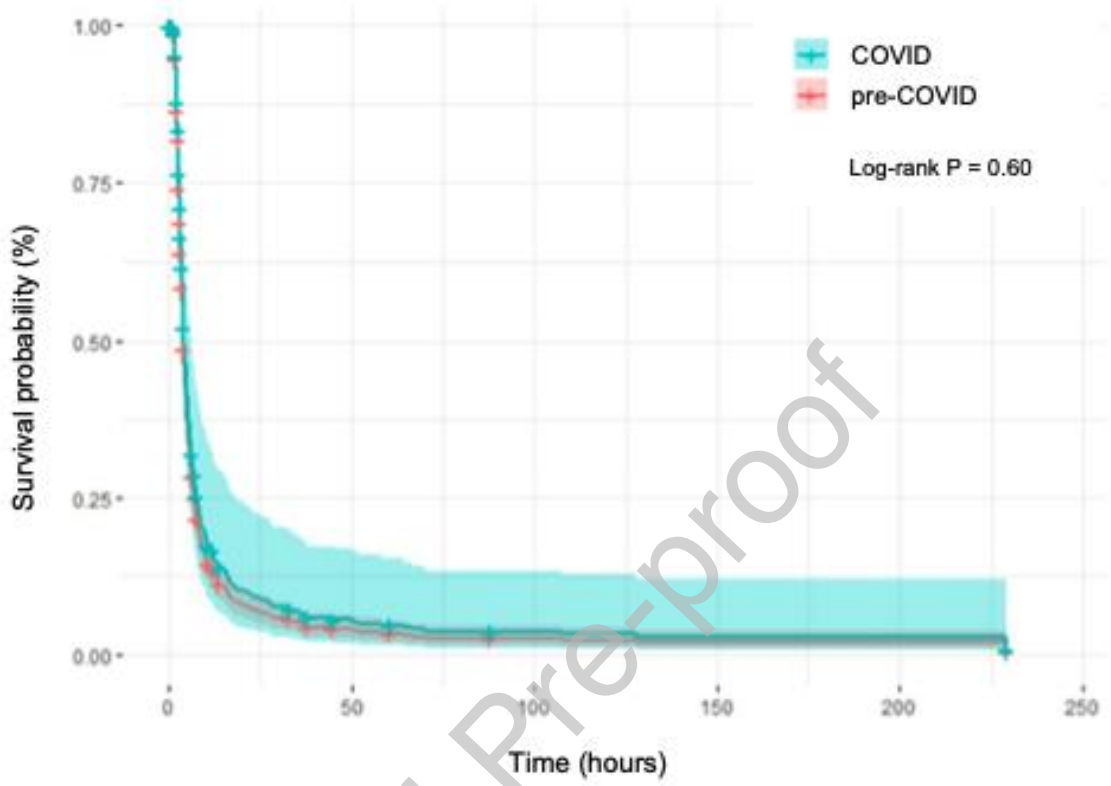

Figure 2: Shown here is the Kaplan-Meier survival curve of novel transplant ICU (N-TICU) length of stay (N-TLOS) for pre-COVID and COVID groups following orthotopic liver transplantation. The light blue band demonstrates the confidence intervals for the COVID group, while the light red band demonstrated the confidence intervals for the pre-COVID group. These results demonstrate that there was no significant difference between TICU length of stay when comparing the COVID and pre-COVID cohorts.

Figure 3: Kaplan-Meier survival curve of hospital length of stay for pre-COVID and COVID groups following OLT

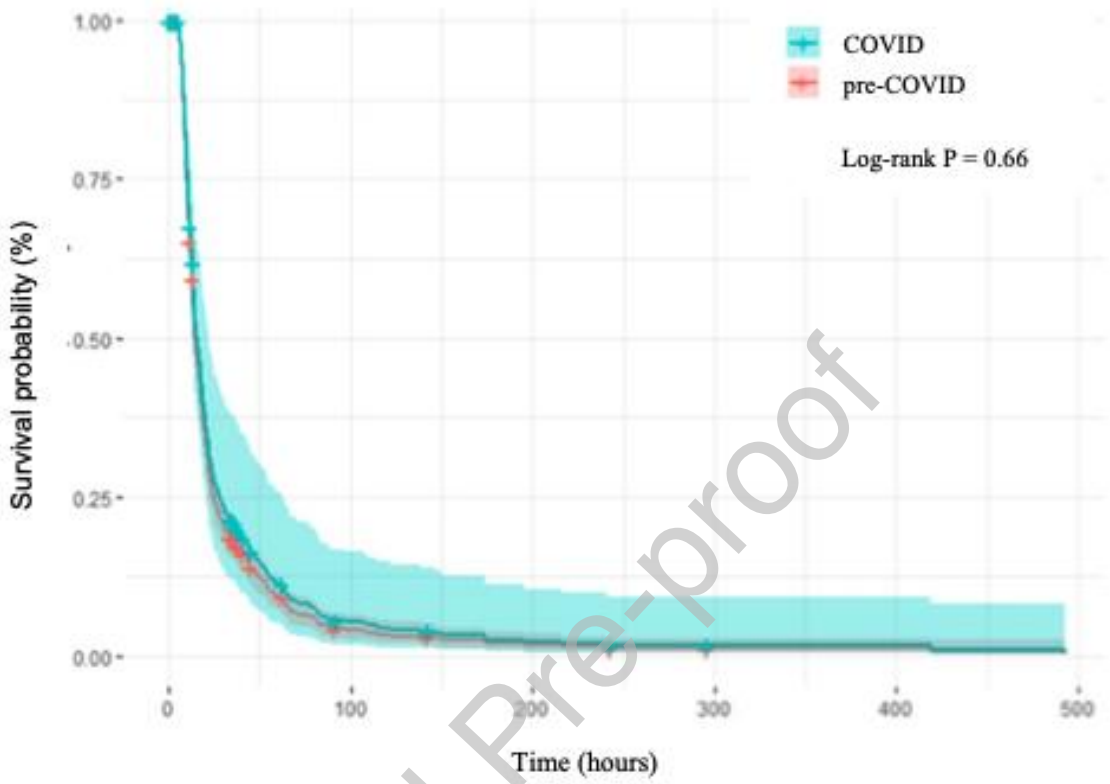

Figure 3: The graph shows the Kaplan-Meier survival curve of hospital length of stay for pre-COVID and COVID groups following orthotopic liver transplantation. The light blue band demonstrates the confidence intervals for the COVID group, while the light red band demonstrated the confidence intervals for the pre-COVID group. These results demonstrate that there was no significant difference between hospital length of stay when comparing the COVID and pre-COVID cohorts.

Table 1. Comparison of Patient Demographic Data Among Liver Transplant Patients

	Pre-COVID (n = 493)	COVID (n = 30)	P-value
Age, years, mean (SD)	54.8 (12.9)	52.8(15.3)	0.48
Male, n (%)	324 (65.7)	18 (60.0)	0.56
BMI, kg/m2, mean (SD)	28.1 (5.9)	29.2 (7.0)	0.45
Liver disease Subtype, n (%)			
Alcoholic cirrhosis	29 (5.9)	13 (43.3)	<0.001
Hepatocellular carcinoma	79 (16.0)	8 (26.7)	0.13
Liver disease characteristics, n (%)			
Ascites	14 (2.8)	21 (70.0)	<0.001
Spontaneous bacterial peritonitis	34 (6.9)	10 (33.3)	<0.001
Variceal bleed	17 (3.4)	17 (56.7)	<0.001
Hepatic encephalopathy	34 (6.9)	16 (53.3)	<0.001
Hepatorenal syndrome	7 (1.4)	5 (16.7)	<0.001
MELD score			0.05
MELD ≤ 9	141 (28.6)	8 (26.7)	
MELD 10 to 19	105 (21.3)	13 (43.3)	
MELD 20 to 29	110 (22.3)	5 (16.7)	
MELD ≥ 30	137 (27.8)	4 (13.3)	
Medical comorbidities, n (%)			
Coronary artery disease	15 (3.0)	4 (13.3)	0.02
Cardiac arrhythmias	9 (1.8)	3 (10.0)	0.03
Hypertension	109 (22.1)	14 (46.7)	0.01
Chronic kidney disease	22 (4.5)	10 (33.3)	<0.001
Type II diabetes mellitus	90 (18.3)	9 (30.0)	0.15
Transplantation characteristics, n (%)			
History of prior transplant	34 (6.9)	1 (3.3)	0.71
Simultaneous liver-kidney transplant	58 (11.8)	5 (16.7)	0.39
Donor type			<0.001
Deceased, circulatory death	24 (4.9)	8 (26.7)	
Deceased, brain death	418 (84.8)	19 (63.3)	
Living	51 (10.3)	3 (10.0)	

* "P-value" refers to the statistical significance of differences between the two groups, assessed by t-test for age, body mass index (BMI), and length of stay; and by $\chi 2$ test or Fisher's exact test for the remaining variables.

MELD, model for end-stage liver disease.

Table 2. Primary Outcome Measures

	Pre-COVID (N = 493)	COVID (N = 30)	P-value
N-TLOS, median [IQR]	3.8 [2.6, 6.8]	4.5 [3.0, 6.8]	0.6
HLOS, median [IQR]	14.2 [9.7, 23.9]	14.5 [12, 34]	0.66

* "P-value" refers to the statistical significance of differences between the two groups assessed by the log-rank test.

N-TLOS, novel TICU length of Stay. HLOS, hospital length of stay

Table 3. Secondary Outcome Measures

	Pre-COVID (N = 493)	COVID (N = 30)	P-value	Total (N = 523)
Time-to-extubation				
Median [IQR]	28.7 [20.6, 50.7]	26.8 [17.4, 40.8]	0.35	28.5 [20.0, 50.6]
Missing data, n (%)	98 (19.9%)	3 (10.0%)		101 (19.3%)
1-year patient survival, n (%)				
Survival > 1 year	430 (87.2%)	28 (93.3%)	0.55	458 (87.6%)
Survival < 1 year	59 (12.0%)	2 (6.7%)		61 (11.7%)
Missing	4 (0.8%)	0 (0%)		4 (0.8%)
1-year graft survival, n (%)				
Survival > 1 year	423 (85.8%)	28 (93.3%)	0.43	451 (86.2%)
Survival < 1 year	66 (13.4%)	2 (6.7%)		68 (13.0%)
Missing data	4 (0.8%)	0 (0%)		4 (0.8%)
Readmission to ICU, n (%)				
No	405 (82.2%)	24 (80.0%)	0.68	429 (82.0%)
Yes	74 (15.0%)	6 (20.0%)		80 (15.3%)
Missing data	14 (2.8%)	0 (0%)		14 (2.7%)

* "P-value" refers to the statistical significance of differences between the 2 groups assessed by the Kruskal-Wallis test for time-to-extubation, and by chi-square for the remaining variables.

Table 4. Cox Proportional Hazards Regression Analysis for TICU and Hospital LOS

Models	TLOS HR* (95% CI)	P-value	HLOS HR* (95% CI)	P-value
Traditional approach without IPTW				
Pre-COVID liver transplants	Reference		Reference	
COVID liver transplants	0.63 (0.37-1.07)	0.09	0.66 (0.38-1.16)	0.15
After IPTW with stabilized weights only				
Pre-COVID liver transplants	Reference		Reference	
COVID liver transplants	0.92 (0.56-1.50)	0.73	0.85 (0.56-1.29)	0.44
After IPTW with stabilized & trimmed weights				
Pre-COVID liver transplants	Reference		Reference	
COVID liver transplants	0.91 (0.67-1.23)	0.55	0.90 (0.65-1.25)	0.52

* Hazard ratio (HR) represents the relative probability of hospital discharge at any given time during TICU or hospitalization. HR > 1 means that more likely to be discharged early than the reference group.

TICU, transplant ICU; TLOS, transplant ICU length of stay; HLOS, hospital length of stay; IPTW, inverse probability treatment weighting.